

# GMRT search for 150 MHz radio emission from the transiting extrasolar planets HD189733 b and HD209458 b<sup>\*</sup>

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## ABSTRACT

We report a sensitive search for meter-wavelength emission at 150 MHz from two prominent transiting extrasolar planets, HD189733b and HD209458b. To distinguish any planetary emission from possible stellar or background contributions, we monitored these systems just prior to, during, and after the planet's eclipse behind the host star. No emission was detected from HD209458 b with a  $3\sigma$  upper limit of 3.6 mJy. For HD189733 b we obtain a  $3\sigma$  upper limit of 2.1 mJy and a marginal  $2.7\sigma$  detection of  $\sim 1900 \pm 700 \mu\text{Jy}$  from a direction just  $13''$  from the star's coordinates (*i.e.*, within the beam), but its association with the planet remains unconfirmed. Thus, the present GMRT observations provide unprecedentedly tight upper limits for meter wavelengths emissions from these nearest two transiting type exoplanets. We point out possible explanations of the non-detections and briefly discuss the resulting constraints on these systems.

**Key words.** Stars: planetary systems - Stars: coronae - Techniques: interferometric

## 1. Introduction

Because the radio-frequency emission from planets is expected to be strongly influenced by their interaction with the magnetic field and corona of the host star, the physics of this interaction can be effectively constrained by obtaining good measurements of the properties of the planetary radio emission. Therefore, in parallel with theoretical estimates for radio emission from a large number of extrasolar planets (*e.g.*, Grießmeier et al. 2007), searches have been undertaken for decameter- and meter-wavelength radio emission from a few carefully selected extrasolar planets (*e.g.*, Bastian et al. 2000; Ryabov et al. 2004; Winterhalter et al. 2005; George & Stevens 2007; Lazio & Farrell 2007; Smith et al. 2009) and, most recently, by Lecavelier des Etangs et al. (2009) at 244 and 610 MHz and Lazio et al. (2010) at 325 and 1425 MHz with much improved sensitivity. Based on the theoretical estimates, radio detections seem currently feasible only provided that the planets are  $10^3$  to  $10^4$  times stronger emitters than Jupiter. However, the extreme physical conditions of “hot-Jupiters” could make this realizable, *e.g.*, through a massive infall of Poynting flux on them (Zarka 2007). This provides the physical justification for the radio-magnetic scaling law proposed by Zarka et al. (2001). In any event, it should be borne in mind that all existing estimates of cyclotron maser decametric emission are based on a host of unknowns, *e.g.*, stellar winds, coronal density, and stellar and planetary magnetic fields.

Practically all searches for radio emission from exoplanets have been carried out at metre wavelengths and, to date, the results have been negative. The telescopes used include UTR (10-30 MHz,  $\sigma \sim 1.6 \text{ Jy}$ ), VLA (74 MHz,  $\sigma \sim 50 \text{ mJy}$ ; 325 MHz,  $\sigma \sim 0.58 \text{ mJy}$ ; 1425 MHz,  $\sigma \sim 16 \mu\text{Jy}$ ), and GMRT (150 MHz,  $\sigma \sim 10 \text{ mJy}$ ; 244 MHz,  $\sigma \sim 0.7 \text{ mJy}$ ; 610 MHz,  $\sigma \sim 50 \mu\text{Jy}$ ; see review in Lazio et al. 2009). At these low frequencies, the principal contributors to the noise level are the sky background, radio frequency interference and the ionospheric scintillations that distort the incoming signal and increase the noise. Hence, interferometric observations of high sensitivity and resolution hold considerable promise. In particular, the Giant Metrewave Radio Telescope (GMRT), a 30-km baseline array consisting of 30 dishes of 45 metre diameter each (Swarup 1990), seems very appealing for this purpose. In a recent paper (Lecavelier des Etangs et al. 2009) we reported the first GMRT search, which was targeted at the planet HD189733 b, one of the best candidates among the known “hot-Jupiter” type extrasolar planets (Sect. 2.1). Our search was more than an order of magnitude more sensitive than the previously reported deepest search for meter-wavelength emission from this system by Smith et al. (2009), who observed it at 307-347 MHz. For stellar+planetary emission toward HD189733 b we obtained  $3\sigma$  upper limits of 2 mJy at 244 MHz and  $160 \mu\text{Jy}$  at 610 MHz. Because one of the plausible explanations for the non-detection is that the emission frequency is lower owing to a weak planetary magnetic field, we decided to make the radio search at 150 MHz, which is the lowest frequency accessible using the GMRT. The targets chosen are the two most prominent transiting hot-Jupiters: HD189733 b (Bouchy et al. 2005) and HD209458 b (Mazeh et al. 2000; Charbonneau et al. 2000).

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\* Data for this observations can be retrieved electronically on the GMRT archive server <http://ncra.tifr.res.in/~gmrtarchive> and by request to [archive@gmrt.ncra.tifr.res.in](mailto:archive@gmrt.ncra.tifr.res.in).

## 2. The targets and the observational strategy

### 2.1. HD189733 b

Located just 19.3 parsec away, HD189733 b is one of the most prominent extrasolar planets known (Bouchy et al. 2005). With a semi-major axis of 0.03 AU and an orbital period of 2.2 days, it belongs to the class of “very hot-Jupiters”. More importantly, because this planet is seen to transit its parent star, the transits and eclipses have been used to probe the planet’s atmosphere and environment (*e.g.*, Charbonneau et al. 2008; Désert et al. 2009).

HD189733 b orbits a small and bright main-sequence K-type star and shows a transit occultation depth of  $\approx 2.5\%$  at optical wavelengths (Pont et al. 2007). The planet has a mass  $M_p = 1.13$  Jupiter mass ( $M_{\text{Jup}}$ ) and a radius  $R_p = 1.16$  Jupiter radius ( $R_{\text{Jup}}$ ) in the visible (Bakos et al. 2006; Winn et al. 2007). The orbital period of the planet (2.21858 days) and its transit epochs have been measured precisely (Hébrard & Lecavelier des Etangs 2006; Knutson et al. 2009). Sodium absorption has been detected in the planet’s atmosphere by ground-based observations (Redfield et al. 2008). Using the ‘Advanced Camera for Surveys’ onboard the Hubble Space Telescope (HST), Pont et al. (2008) detected atmospheric haze, which is interpreted as Mie scattering by small particles (Lecavelier des Etangs et al. 2008a). Carbon monoxide molecules have been tentatively invoked to explain the excess absorption seen at  $4.5 \mu\text{m}$  (Charbonneau et al. 2008; Désert et al. 2009). Absorption in Lyman- $\alpha$  observed with the HST/ACS is explained in terms of atomic hydrogen escaping from the planet’s exosphere at a rate of  $10^7$ - $10^{11}$  g/s (Lecavelier des Etangs et al., 2010). Recent XMM-Newton observations show flare-type X-ray emission from HD189733 and a possible softening of the X-ray spectrum during the planetary eclipse (Pillitteri et al. 2010). Spectro-polarimetry has revealed the strength and topology of the stellar magnetic field, which reaches up to 40 G (Moutou et al. 2007). Fares et al. (2010) found a variable magnetic field on the surface of the star from 22 to 36 G. Using a model to extrapolate the magnetic field, the authors concluded that the average magnetic field should be in the range 4-23 mG at the distance of the planet.

### 2.2. HD209458 b

Located 47 parsecs away, HD209458 b is the second-closest transiting hot-Jupiter after HD189733 b. This planet is the first extrasolar planet for which atmosphere and exosphere have been probed using the transit technique (Charbonneau et al. 2002; Vidal-Madjar et al. 2003). With a semi-major axis of 0.047 AU and an orbital period of 3.5 days (Mazeh et al. 2000) this planet is a prominent member of the “hot-Jupiter” class. As for HD189733 b, the planetary transits and eclipses have been used to probe the planet’s atmosphere and environment (*e.g.*, Sing et al. 2008; Lecavelier des Etangs et al. 2008b).

HD209458 b orbits a main-sequence G-type star and shows a transit occultation depth of  $\approx 1.5\%$  at optical wavelengths (Sing et al. 2008). The planet has a mass  $M_p = 0.69$  Jupiter mass ( $M_{\text{Jup}}$ ) and a radius  $R_p = 1.32$  Jupiter radius ( $R_{\text{Jup}}$ ). Despite the large body of data available for this system, little is known about its magnetospheric activity or the star-planet interactions.

Nonetheless, a striking outflow of hydrogen gas has been detected (Vidal-Madjar et al. 2003, 2008; Ehrenreich et al. 2008); these atoms are probably expelled at high velocity caused by the stellar radiation pressure (Lecavelier des Etangs et al. 2008c). High velocity ions (C II, Si III), possibly at high temperature, have also been detected with HST/STIS and HST/COS (Vidal-Madjar et al. 2004; Ben-Jaffel & Sona Hosseini 2010; Linsky et al. 2010). Possible auroral dayglow emission from the planet’s atmosphere was reported by France et al. (2010), but the excitation mechanism for the detected transition of the  $\text{H}_2$  molecules remains unclear.

### 2.3. The planetary eclipses at 150 MHz

The atmosphere and environment of transiting planets are studied using the planetary eclipse technique, that is, by subtracting the signal received when the planet is hidden behind the star from observations made before and after the eclipse. This allows a reliable extraction of the contribution of the planet and its atmosphere to the received signal. This technique has made possible the detection of thermal infrared emission from an extensive sample of extrasolar planets using both Spitzer (*e.g.*, Charbonneau et al. 2005; Deming et al. 2005; Stevenson et al. 2010) and several ground based telescopes (*e.g.*, Sing & López-Morales 2009; Croll et al. 2010; Cáceres et al. 2011; de Mooij et al. 2011). Using Spitzer spectroscopy of planetary eclipses, infrared spectra of the atmosphere of HD189733 b have revealed signatures of  $\text{H}_2\text{O}$  absorption and possibly weather-like variations in the atmospheric conditions (Grillmair et al. 2009; see Seager & Deming 2010 for a review on the Spitzer observations of planetary atmospheres).

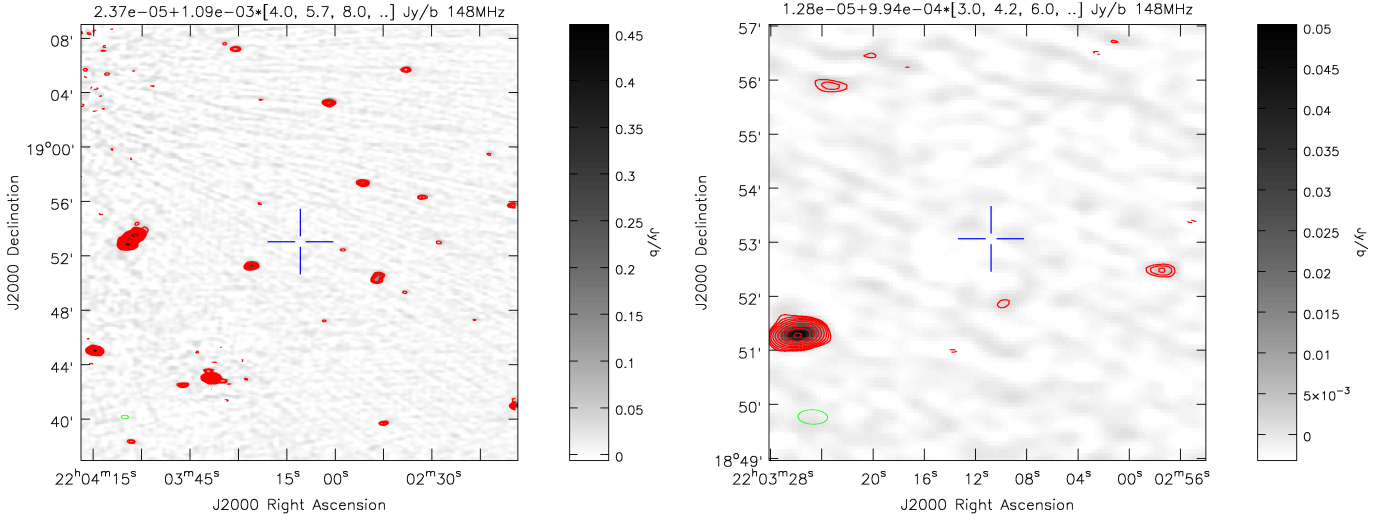
We have adopted a similar strategy by monitoring the radio flux from the HD189733 and HD209458 systems before, during, and after the eclipse of the respective planet. For this we developed a technique to extract the time series of the target’s radio continuum flux from the interferometric visibilities measured with the GMRT (Sect. 3). By comparing the radio flux levels at different phases of the planetary orbit, we can thus distinguish between any radio emission contributed by the planet and by the host star (or any other background source within the synthesized beam).

The choice of 150 MHz, the lowest frequency available at GMRT, was intended to increase the likelihood of detection for a weak planetary magnetic field. Indeed, in our previous search using GMRT the non-detection down to the very low limit of a few hundreds of  $\mu\text{Jy}$  is most plausibly explained in terms of a weak planetary magnetic field and the low gyrofrequency of the resulting electron-cyclotron maser radiation.

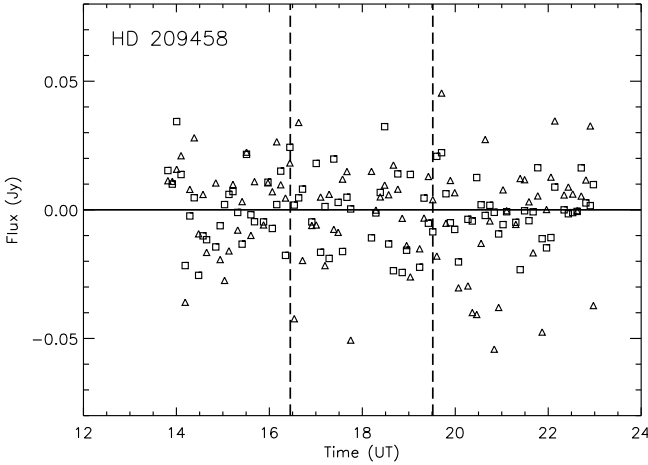
## 3. Observations and data analysis

The GMRT 150 MHz observations of the HD189733b field were made on 2009 August 15, and of HD209458b field on 2009 September 9. For each observation, the phase centre was set at the star’s position :  $\alpha_0 = 20^{\text{h}}00^{\text{m}}43.7^{\text{s}}$ ,  $\delta_0 = +22^{\circ}42'39''$  (J2000) for HD189733, and  $\alpha_0 = 22^{\text{h}}03^{\text{m}}10.8^{\text{s}}$ ,  $\delta_0 = +18^{\circ}53'03''$  (J2000) for HD209458.

The HD189733 observations started at 13h30m UT and finished at 22h30m UT, covering the full passage of the



**Fig. 1.** GMRT image of HD209458 field at 150 MHz. The green ellipse in the lower left corner of each image shows the half-power beamwidth ( $33'' \times 16''$  at a position angle of  $88^\circ$ ). The blue cross indicates the center of field toward HD209458. In the left panel the contour levels are at 4.0, 5.7, and 8.0 times the image RMS of  $1100 \mu\text{Jy per beam}^{-1}$ . In the right panel the contour levels are at 3.0, 4.2, and 6.0 times the center field RMS of  $990 \mu\text{Jy per beam}^{-1}$ . Negative contours appear as dashed lines.



**Fig. 2.** Time series of the flux density in the direction of HD209458, for a sampling window of 339 seconds. The vertical dotted lines indicate the beginning and the end of the planet's eclipse behind the host star. Triangles and squares correspond to the RR and LL polarizations, respectively.

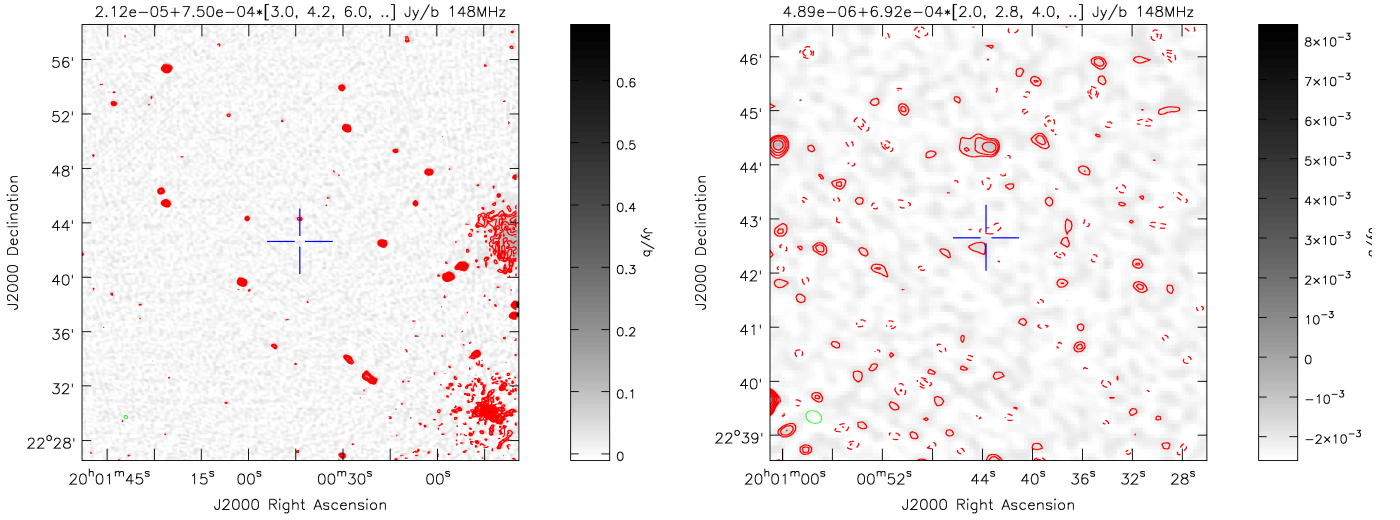
target in the visibility window of the GMRT sky and also covering the planet's eclipse behind the star, which took place between 17h27m UT and 19h16m UT. The HD209458 observations started at 14h30m UT and finished at 23h30m UT, encompassing the planet's eclipse from 16h27m UT to 19h31m UT.

The center frequency of the receiver was set at 148 MHz, with a bandwidth of 16 MHz. The visibility integration time was 2.09 second. For each of the two observing runs the total observation time was close to 9 hours, including the target field and the calibration sources.

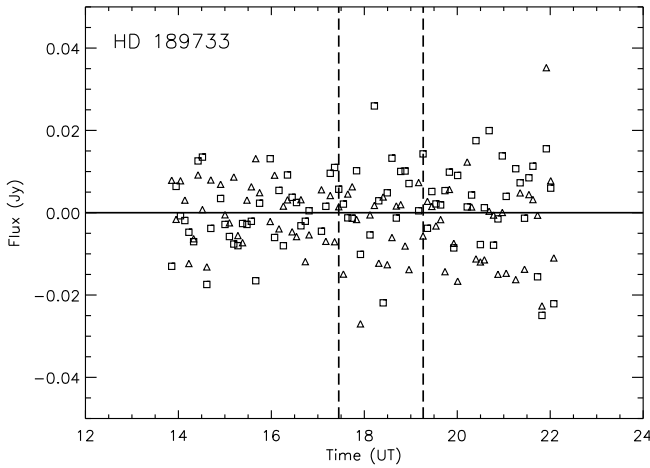
3C48 was observed as the primary flux density and bandpass calibrator. The phase calibrators used are J1924+334 for HD189733 and J2251+188 for HD209458; they were observed repeatedly during the observations. The total data acquisition time on the target field was 7.2 hours for HD189733 and 7.8 hours for HD209458.

The data reduction was carried out mainly using the AIPS++ package (version: 1.9, build #1556). After applying bandpass corrections using 3C48, gain and phase variations of individual antennas were quantified and used for calibrating the flux density, bandpass, gain, and phase for the target field data. For 3C48 we took a flux density of  $64.4 \text{ Jy}$  at 150 MHz (Perley & Taylor 1999). The calibrated flux densities toward HD189733 have also been corrected upward by a factor 1.6, which is the ratio between the system temperatures toward the direction of HD189733 ( $T_{\text{sys}}(150\text{MHz}) \approx 1014 \text{ K}$ ) and the direction of the calibrator 3C48 ( $T_{\text{sys}}(150\text{MHz}) \approx 642 \text{ K}$ ).

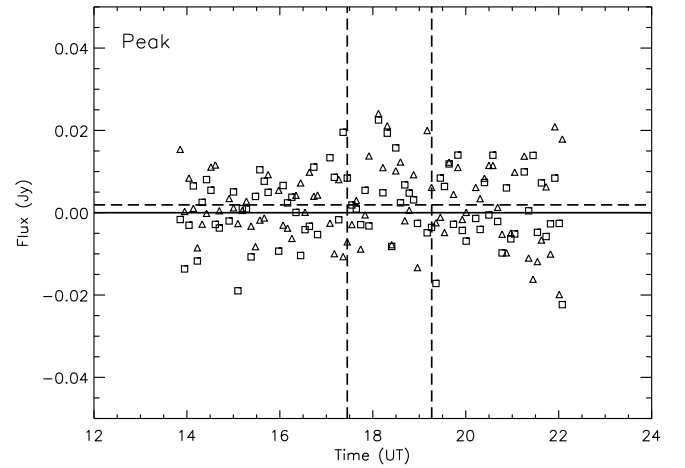
While calibrating the visibilities, bad data points were flagged at various stages. The data for the antennas with relatively large errors in antenna-based gain solutions were examined and flagged over the corresponding time ranges. Some baselines were flagged, in view of large closure errors found on the bandpass calibrator. Channel- and time-based flagging of the data points corrupted by radio frequency interference (RFI) was made by applying a median filter with a  $6\sigma$  threshold. Cases of residual errors above  $5\sigma$  were also flagged after a few rounds of imaging and self-calibration. The system temperature ( $T_{\text{sys}}$ ) was found to vary among the antennas and also with the ambient temperature and elevation (Sirothia 2009). In the absence of regular  $T_{\text{sys}}$  measurements for GMRT antennas, this correction was estimated from the residuals of the calibrated data with respect to the model data. The corrections were then applied to the data. The final image was made after several rounds of phase self-calibration until the change in S/N ratio between two successive rounds became less than 1%. Lastly,



**Fig. 3.** Same as Fig. 1 for the HD189733 field at 150 MHz. The half-power beamwidth is  $18'' \times 13''$  at a position angle of  $70^\circ$ . In the left panel the contour levels are at 3.0, 4.2, and 6.0 times the image RMS of  $750 \mu\text{Jy per beam}^{-1}$ . In the right panel the contour levels are at 2.0, 2.8, and 4.0 times the center field RMS of  $690 \mu\text{Jy per beam}^{-1}$ , showing the 2.7- $\sigma$  source at  $13''$  from HD189733 to the southeast of the target position (see text).



**Fig. 4.** Time series of the flux density in the direction of HD189733, for a sampling window of 339 seconds. The vertical dashed lines indicate the beginning and the end of the planet's eclipse behind the host star. Triangles and squares correspond to the RR and LL polarizations, respectively.



**Fig. 5.** Time series of the flux density in the direction  $13''$  from HD189733 (see text), with the same legend as in Figure 4. The dashed horizontal line shows the flux level of this peak source at 1.9 mJy.

we applied one round of amplitude self-calibration, where the data were normalized using the median gain found for the entire data. The image was then corrected for the primary beam shape taken to be a Gaussian with a FWHM of  $173.8'$  at 153 MHz. For the central  $8' \times 8'$  regions shown in Fig. 1 and 3,  $\sigma = 0.70 \text{ mJy/beam}$  for the HD189733 field and  $\sigma = 1.0 \text{ mJy/beam}$  for the HD209458 field.

After completing the imaging, we generated the light curves for a synthesized-beam size region ( $\sim 20''$ ) centered on the coordinates of the two target stars. To obtain these light curves, we calculated model visibilities using the sources detected in the entire field-of-view excluding a syn-

thesized beam-wide region centered on the target position ( $\alpha_0, \delta_0$ ); we then subtracted this model from the final calibrated visibility data. The residual visibility data (RVD) were then phase-centered on  $\alpha_0, \delta_0$  and can be averaged for any desired time bins to generate the light curves. Figures 2 and 4 show the resulting light curves for the two targets.

From the light curves we can estimate a flux density at the target position for any given time interval with its associated error bar. The flux density is estimated using a weighted mean of the data points in the light curves, where each measurement has a weight proportional to the number of visibilities used to obtain it. We checked that the light curves are free of correlated noise and that the RMS

decreases with the square root of the bin size. The error bars of the estimated flux densities are hence calculated as the weighted standard deviation of the data points divided by the square root of the number of points (for the 339 seconds bins we have a total of 160 and 176 data points in the two polarizations for HD189733 and HD209458, respectively). The resulting error bars on the estimated flux densities for the full integration time are found to be consistent with the independently estimated RMS of the final images:  $\sim 1.0$  mJy for HD209458 and  $\sim 0.7$  mJy for HD189733.

## 4. Results

### 4.1. HD209458b

For the stellar+planetary emission, the GMRT 150 MHz image of the HD209458 field shows no source at the target coordinates, setting a  $3\sigma$  upper limit of about 3.6 mJy (Fig. 1).

Using the light curve, we also searched for the planet's emission at different orbital phases and any radio flares. With average flux densities of  $1.54 \pm 2.02$  mJy,  $-1.78 \pm 2.22$  mJy, and  $-1.39 \pm 2.03$  mJy, respectively, before, during and after the secondary transit, no eclipse signature has been found. Likewise, the running averages of the light curve, taken for time intervals between 1 and 30 minutes, revealed no flaring event. In Fig. 2 we choose 339 seconds bin size to plot the light curve, this is a compromise between the apparent noise and the possibility to detect potential short lived emission flares. We therefore conclude a non-detection of planetary radio emission. We note that the planet's eclipse times plotted in Fig. 2 (dashed vertical lines) are computed using the optical size of the planet. If the radio emission originates in a region larger than the planet, the ingress could happen earlier and the egress later. However, emission at frequencies around 150 MHz is expected to originate in the very inner regions of the planetary magnetosphere, and therefore the relevant ingress/egress times are expected to be very similar to those for the planet itself.

### 4.2. HD189733b

The GMRT 150 MHz image in the HD189733 field shows no source at the target coordinates, setting a  $3\sigma$  upper limit of about 2.1 mJy (Fig. 3). We also searched for the planet's emission at different orbital phases and for radio flares using the light curve (Fig. 4). With average flux densities before, during, and after the secondary transit being,  $-0.10 \pm 0.86$  mJy,  $-0.69 \pm 1.73$  mJy, and  $-0.46 \pm 1.51$  mJy respectively, no eclipse signature has been detected for this planet either. Nonetheless, we report a marginal ( $2.7\sigma$ ) detection of  $\sim 1900 \pm 700$   $\mu$ Jy at  $\alpha = 20^{\text{h}}00^{\text{m}}44.4^{\text{s}}$  and  $\delta = +22^{\circ}42'29.9''$  (J2000), which is at  $13''$  with a position angle of  $50^\circ$  from the coordinates of HD189733. The mean level in the light curve obtained in this direction confirms the detection of an emission (Fig. 5). In the direction of this peak, the average flux densities before, during, and after the planetary eclipse are  $1.01 \pm 0.86$  mJy,  $4.43 \pm 1.58$  mJy, and  $0.51 \pm 1.27$  mJy, respectively, which is too noisy to find any eclipse signature. We are consequently unable to reach a conclusion about the planetary or stellar origin of the  $2.7\sigma$  signal detected at 150 MHz.

The  $13''$  shift between the measured position of the peak source and the absolute position of the star corresponds to about 250 AU at the distance of the HD189733 planetary system. However, for a source detected at only a few sigma level, the position uncertainty is about the beam size. With a half-power beamwidth of  $17''$  at the position angle of  $50^\circ$ , this shift is not significant and is well within the position uncertainty. At the same time, the chance of this emission being associated with a background/foreground source is fairly low. Above the measured flux density of 1.9 mJy at 150 MHz we estimate a source density of about 0.3 per square arc minute in the target field, hence the probability of such a chance projection within the synthesized beam is just 5%.

## 5. Discussion

Theoretical and observational aspects of the radio emission from extrasolar planets have been discussed in Zarka (2007), where the generalized concept of flow-obstacle interaction was developed. Accordingly, the clear non-detection toward HD 209458 may be understood because (1) the Earth was outside the planet's emission beam, at least at the time of observation, or (2) the emission is highly variable with flares lasting shorter than the temporal sampling achieved in our observations, or (3) the planetary emission was simply too weak intrinsically, or, perhaps more likely, (4) the planetary emission peaks at frequencies lower than 150 MHz because of the weakness of the planetary magnetic field.

The first two scenarios (observer outside the emission beam, and short-duration flares) have been discussed in Lecavelier des Etangs et al. (2009). Although with a typical beaming angle of  $\sim 50^\circ$ - $60^\circ$  the first scenario cannot be excluded, both explanations for the non-detection are not the favored ones. Intrinsic weakness of the emission and/or its low-frequency appear to be more likely explanations for the non-detections.

### 5.1. Emission flux

For the three mechanisms considered by Greissmeier (2007), i.e., kinetic emission, magnetic emission, and coronal mass ejection, the corresponding radio flux density estimates may reach 0.4, 900, and 30 mJy toward HD189733b, and 0.2, 150 and 10 mJy toward HD209458b, respectively. While all these estimates are only suggestive, the magnetic emission estimate is the highest. Unfortunately, this emission is predicted to peak at just a few MHz, which is much lower than the frequency range covered in the present observations.

Nonetheless, there is another possible scenario for the emission mechanism. For an intense magnetic field (of up to 40 G in the case of HD189733; Moutou et al. 2007) the stellar magnetosphere can extend beyond the orbit of the extrasolar planets given the semi-major axis of just 0.03 AU for HD189733b and 0.047 AU for HD209458b (see discussion in Jardine & Cameron 2008). Assuming that the emission is produced by an interaction between the planetary magnetosphere and the engulfing stellar corona, the use of Eq. 17 and the numerical values from the model of Jardine & Cameron (2008), assuming a 10% efficiency of conversion of the power of accelerated electrons into radio emission and taking an emission beam solid angle of 1.6 sr, the

predicted radio flux densities are about 15 mJy and 3 mJy from HD189733 b and HD 209458 b, respectively. With this model and assuming that the present non-detection of HD189733 b and HD209458 b at 150 MHz is caused by their low intrinsic radio luminosities, the upper limits of 2.1 mJy toward HD189733b and 3.6 mJy toward HD209458b can be translated into upper limits for the stellar coronal density. With a stellar magnetic field strength of 40 G, we therefore obtain upper limits for the stellar coronal densities of 0.4 and 1.2 times the solar coronal density for HD189733 and HD209458, respectively. For HD209458 the stellar field strength,  $B_*$ , is not known, the upper limit for the coronal density is smoothly dependent and scales with  $B_*^{1/3}$ .

## 5.2. Emission frequency

The principal mechanism advocated for radio emission is the electron-cyclotron maser radiation. It occurs at the local gyrofrequency  $f_g = 2.8 (B_p/1 \text{ G}) \text{ MHz}$ , where  $B_p$  is the planet's magnetic field strength. Our results could then be attributed to a weak planetary magnetic field, such that the gyrofrequency falls below our observation frequency of 150 MHz. The corresponding planetary magnetic fields are  $<50 \text{ G}$ . Recall that the Jovian magnetic field estimated from the observed spectral cut-off of its cyclotron radio emission is around 14 G.

Fares et al. (2010) used their stellar magnetic field measurement and its extrapolation to the distance of the planet to estimate the expected flux and frequency of the radio emission. They also estimated that the radio emission should be highly variable with a flux density in the range 7-220 mJy (hence well within the detection limit of our observations), although with a frequency range of 0-6 MHz, possibly extending up to 20 MHz, if the model uncertainties are taken into account. Thus, our non-detections at 150 MHz could also be attributed to weak planetary magnetic field like the one assumed in the Fares et al. model.

Finally, note that the cyclotron maser emission can also be quenched by too high a plasma frequency ( $f_{pe}$ ) in the source region (Zarka 2007). With a 40 G magnetic field, the condition for quenching ( $f_{pe}$  more than a tenth of the cyclotron frequency) implies an electron density higher than about  $1.5 \times 10^6 \text{ cm}^{-3}$  in the low stellar corona, a condition that is not implausible.

## 6. Conclusion

In summary, the 150 MHz observations of HD189733 b and HD209458 b reported here represent an unprecedentedly deep search for planetary radio emission at such low frequencies. The depth of these observations even surpasses some of the theoretical predictions published in the literature. The non-detections could be attributed to an inadequate temporal sampling rate of the observation, beam focusing, or intrinsic emission power being lower than the theoretical predictions. Interestingly, the frequency of our observations would require planetary magnetic fields to be only a few times stronger than that of Jupiter, making weak planetary magnetic fields as a viable explanation for our non-detection. We obtained a 1.9 mJy ( $2.7\sigma$ ) detection of emission from a direction within a beamwidth of the position of HD189733, but the light curve is not sensitive enough to reveal any correlation of the flux with the pal-

net's orbital phase, thus precluding a definitive conclusion about the association of the radio emission with the planet. While we continue our sensitive observations of nearby exoplanets using GMRT at 150 MHz, similar searches at still lower frequencies are highly desirable and should become feasible with UTR2 and LOFAR (in the short-term), and SKA (in the long-term).

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